A New Two Habit Model: Changes and Improvements Compared to the Previous Database

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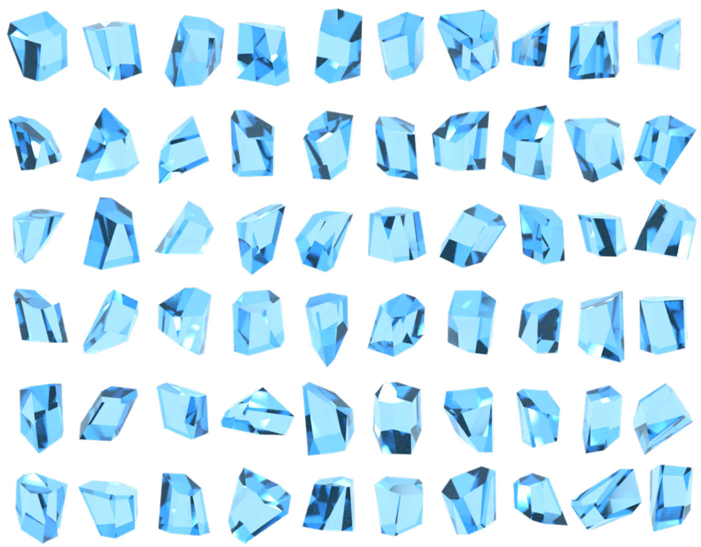
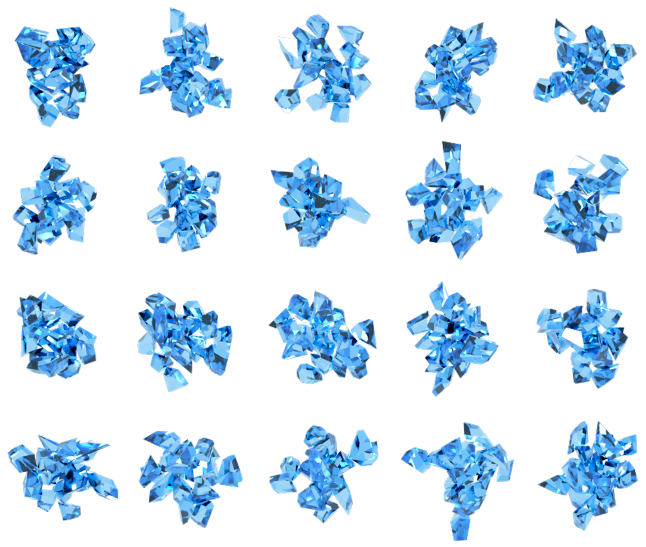
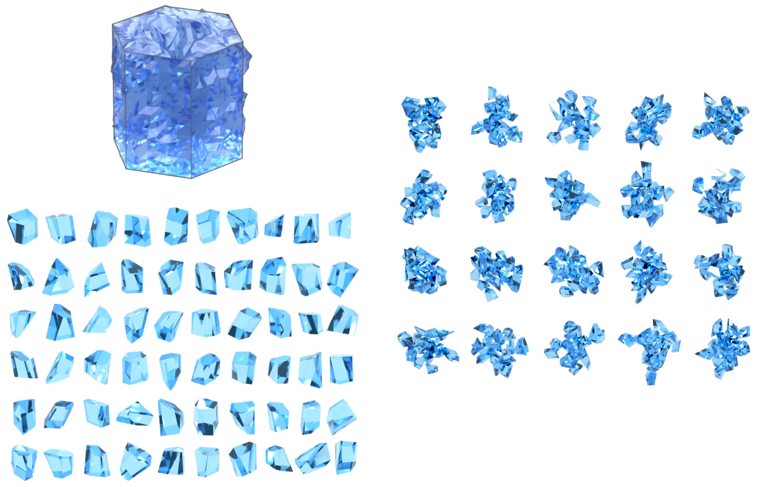
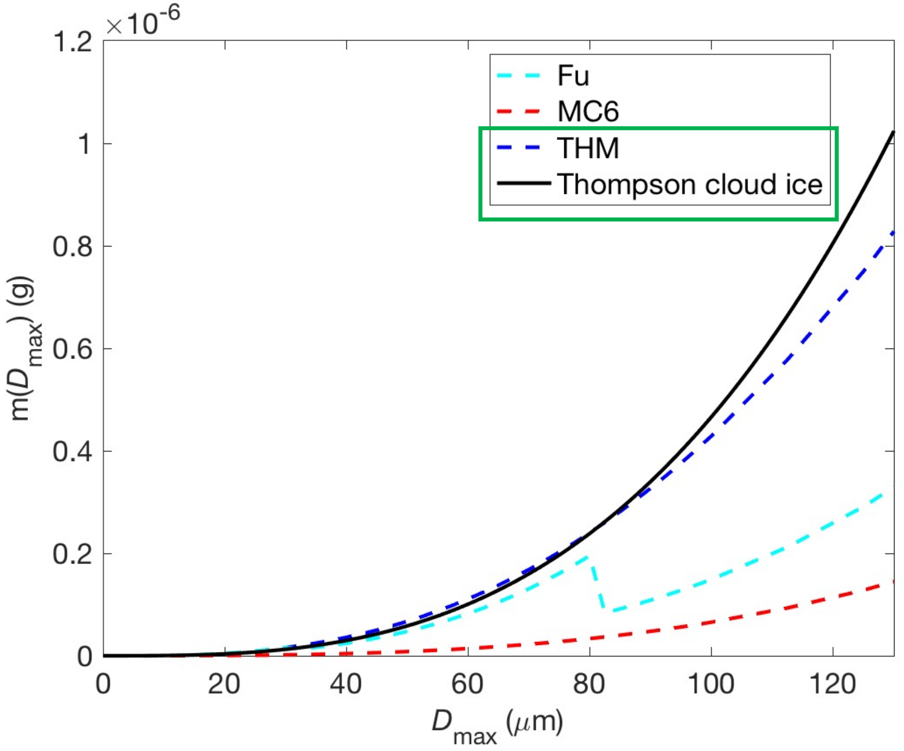




Reasons for a new Two-Habit Model Database

- Current ice cloud models have inaccurate backscattering for moderate size parameters.
    - Improved Geometric Optics Model less accurate.
    - **Affects lidar-based retrievals and assumptions needed to be made.**
- Invariant Imbedding T-Matrix Method (IITM) does not handle small-scale surface roughness.
    - Computationally expensive so only smooth particles used.
- The Two-Habit Model (THM) follows the Thompson et al. 2008 cloud ice scheme than other commonly used single-scattering databases.
    - Used with the Weather Research and Forecasting (WRF) Model.





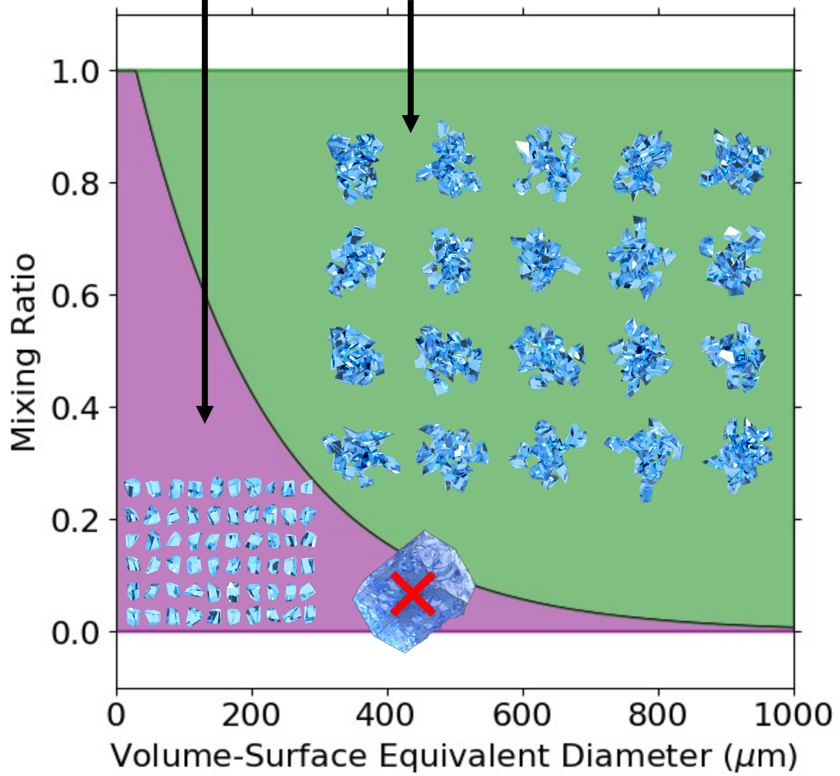
Recap: Full Resolution Two Habit Model (THMv3)

- Full resolution database of new THM developed.
    - **60-particle distorted single column and 20-particle distorted 20-column aggregate ensembles**.
    - Volume-projected area equivalent sphere diameter size characterization (D_{VA}).
        - Maintains microphysical/optical consistency among individual particles of the ensembles.
    - **Same wavelength/size resolution and range as THMv2**.
    - IITM calculations for size parameters < 25 (D_{VA}).
        - Accounted for small-scale surface roughness of hexagonal column by using ensemble of distorted single columns.

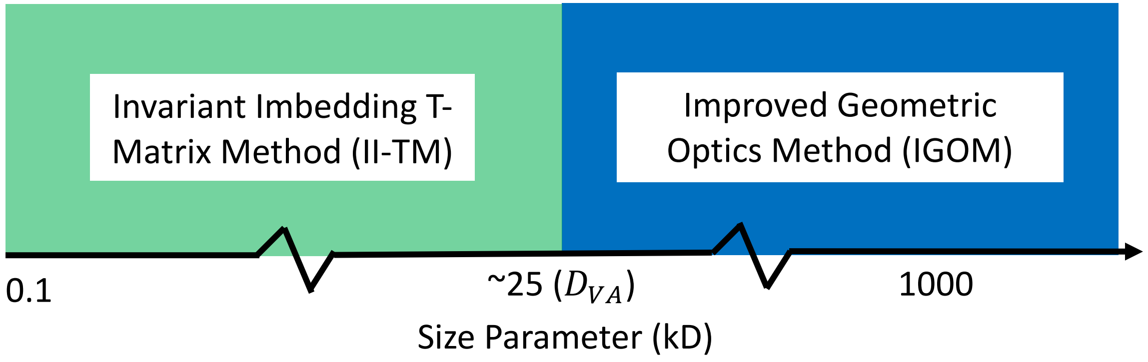
	New THMv3
Wavelength	470 bins (0.2 – 200 μm)
Size (D_{VA})	189 bins (2.0 – 10000.0 μm)

$$f_{single} = \begin{cases} e^{-0.005(D_{VA}-30)}, & D_{VA} \geq 30\mu m \\ 1, & D_{VA} < 30\mu m \end{cases}$$

$$f_{aggregate} = 1.0 - f_{single}$$



THM Computation Methods



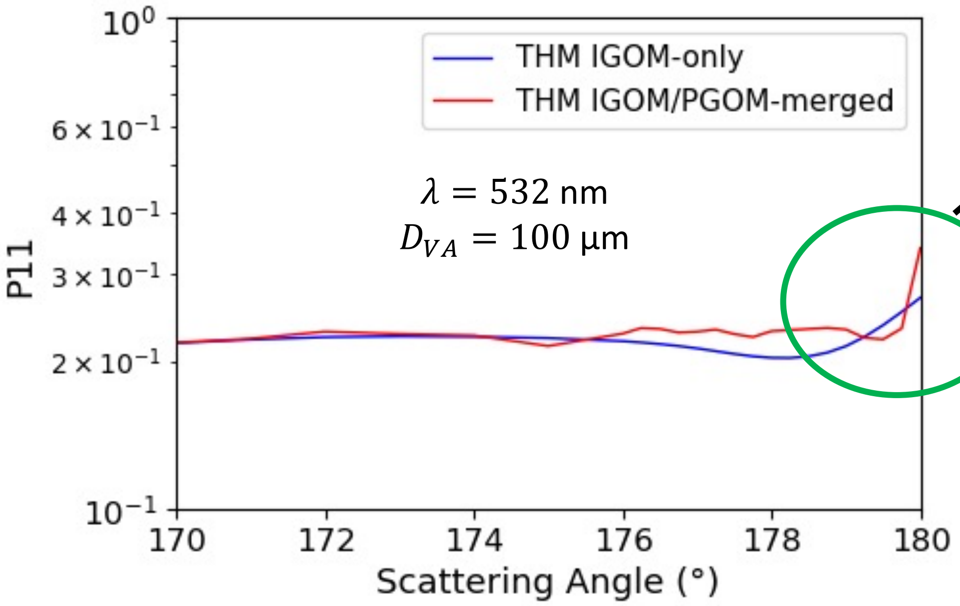
$$D_{VA} = \frac{3V}{2A_p}$$

V: Particle volume

A_p: Projected area

Recap: Lidar Version of THMv3 In Development

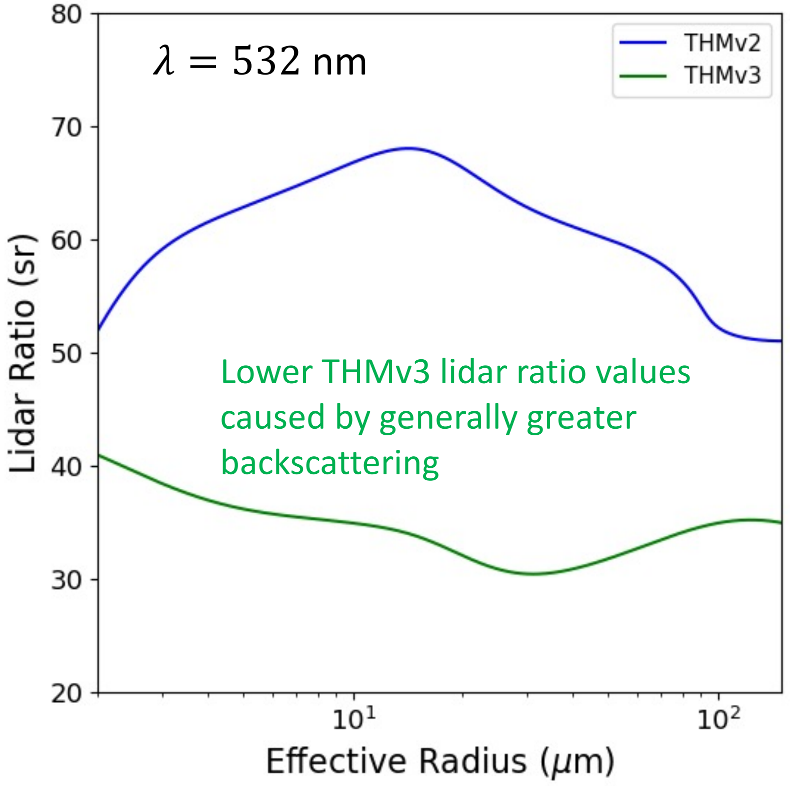
- **355, 532, and 1064 nm** considered for lidar version of THMv3.
- **Physical Geometric Optics Model (PGOM) used for lidar version of THMv3.**
  - Offers more accurate backscattering calculations than IGOM.
  - PGOM-calculated phase matrix truncated and added to existing IGOM-calculated phase matrix.
- Initial THMv3 532 nm lidar ratio results revealed overall lower values than THMv2.
  - Within ranges observed by Seifert et al. 2007 (29 – 33 sr over Indian Ocean).
  - Within ranges observed by Josset et al. 2012 (33 ± 5 sr over the global ocean).
  - More accurate lidar-based retrievals possible.



Lidar Ratio

$$S = \frac{4\pi}{\omega_{bulk} P_{11,bulk}(180°)}$$

ω_{bulk}: bulk scatting albedo
$P_{11,bulk}$: bulk scattering phase function



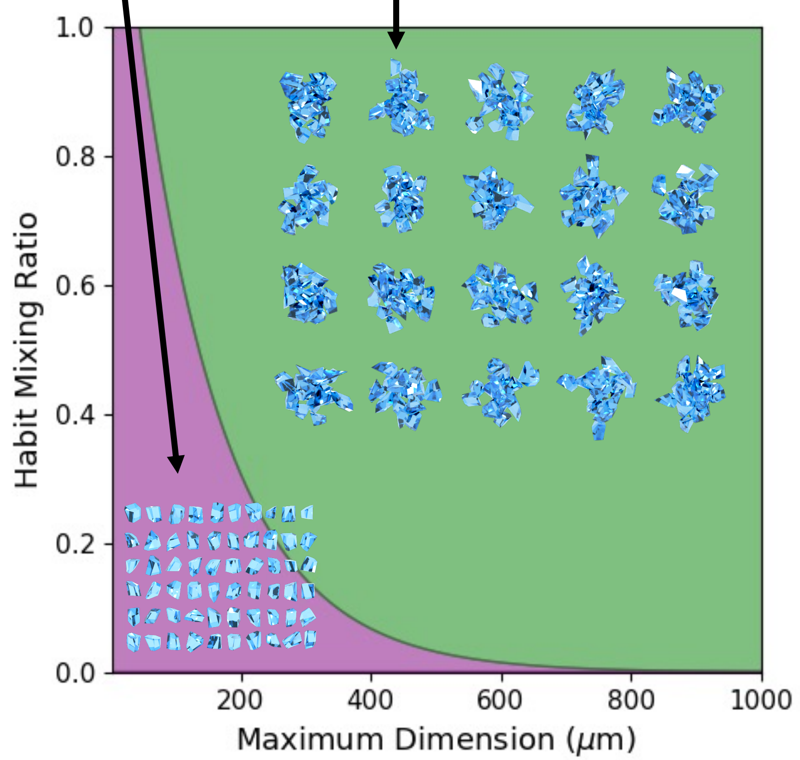
Current Progress: Revised Full Resolution THMv3 Developed

- Revisions/progress performed for full resolution THMv3:
  - **D_{VA} converted to maximum dimension (D_{max}).**
    - Resulted in aggregate volume inconsistency to THMv2 which was corrected.
  - **Adjusted habit fraction formula for microphysical consistency.**
  - Only IITM and IGOM calculations used currently.
    - PGOM backscattering to be eventually added for ultraviolet/visible/near-infrared wavelengths.
  - **Bulk radiative parameterization completed for Fu-Liou radiative transfer model.**

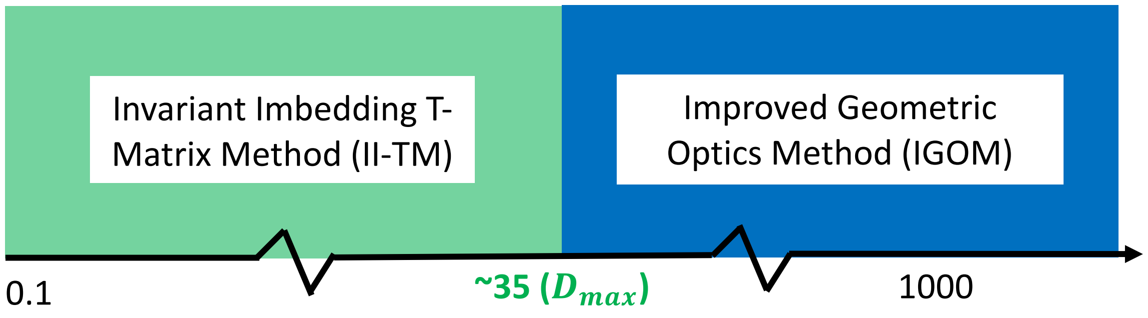
	Revised THMv3
Wavelength	470 bins (0.2 – 200 µm)
Size (D_{max})	189 bins **(2.206 – 11031.337 µm)**

$$f_{single} = \begin{cases} e^{-0.0076(D_{max}-45)}, & D_{max} \geq 45\mu m \\ 1, & D_{max} < 45\mu m \end{cases}$$

$$f_{aggregate} = 1.0 - f_{single}$$

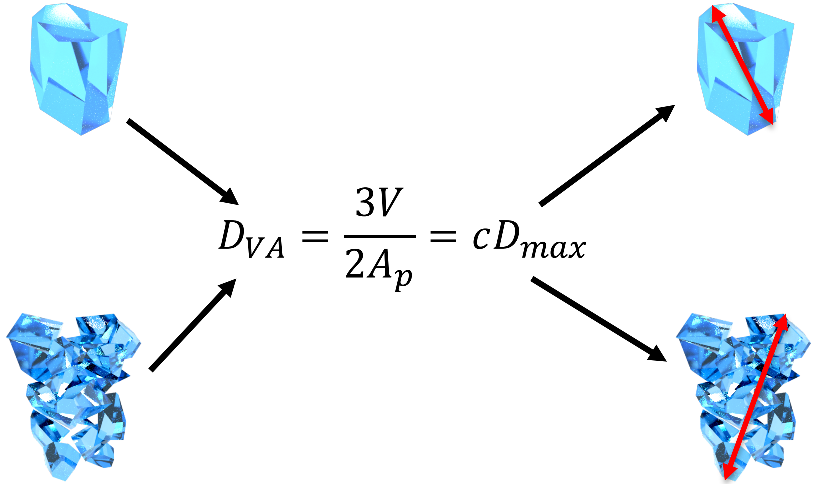


THM Computation Methods



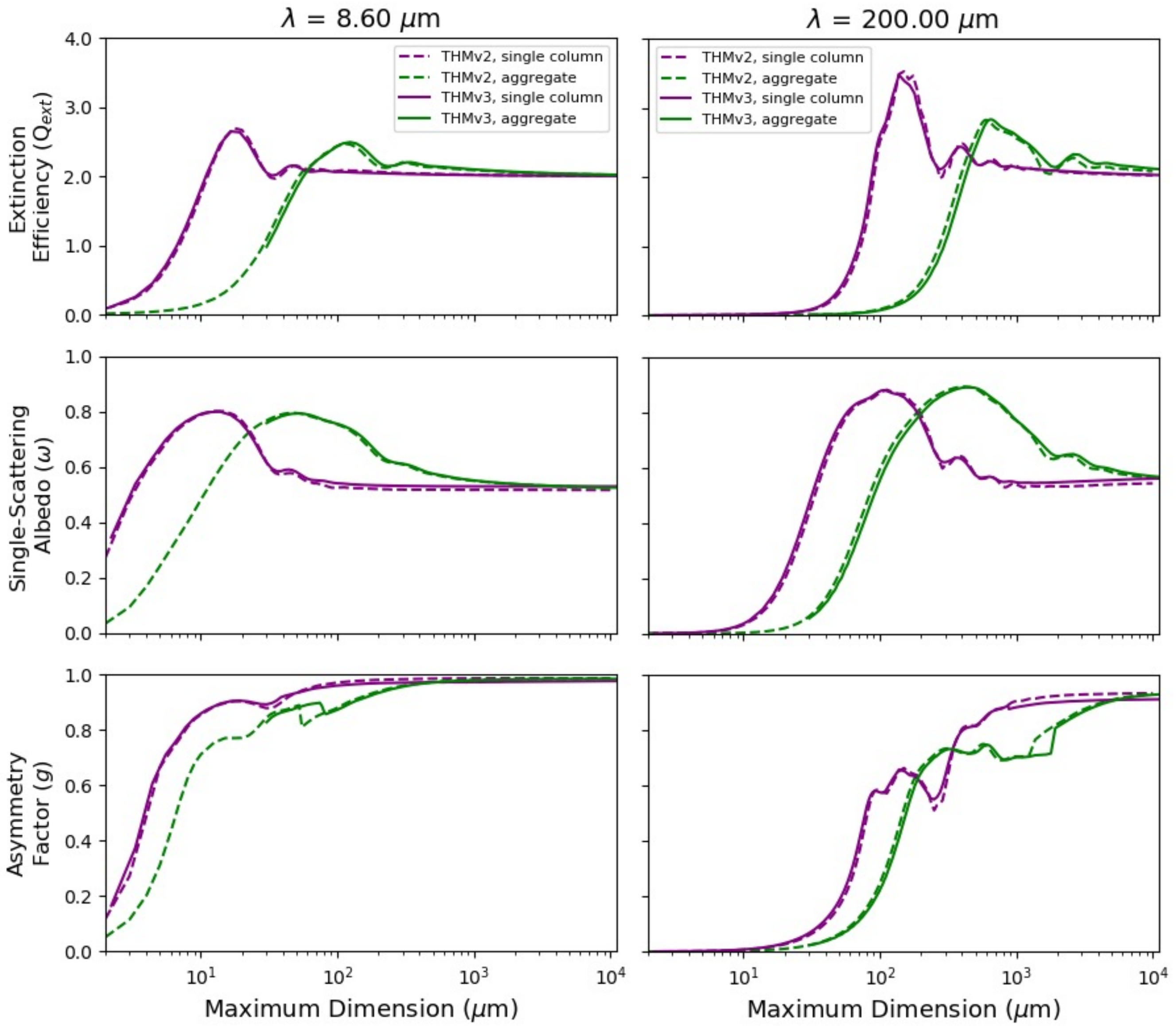
Converting D_{VA} to D_{max} for THMv3 & THMv2 Optical Consistency

- D_{VA} used to maintain microphysical/optical consistency among distorted particles of the ensemble of THMv3.
  - Particle distortion causes changes in particle volume and projected area.
  - Scaling size by D_{max} unreliable.
- **After THMv3 was developed using D_{VA}, particle size converted to D_{max}.**
  - Needed THMv3 and THMv2 to be optically consistent.
  - **A scaling factor (c) applied to D_{VA} values to derive corresponding D_{max} values.**



$$D_{VA} = \frac{3V}{2A_p} = cD_{max}$$

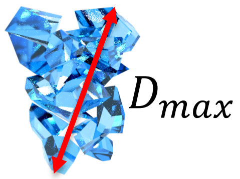
THMv2 & THMv3 Individual Habit Comparisons



Correcting the Aggregate Volume Inconsistency Between THMv2 & THMv3

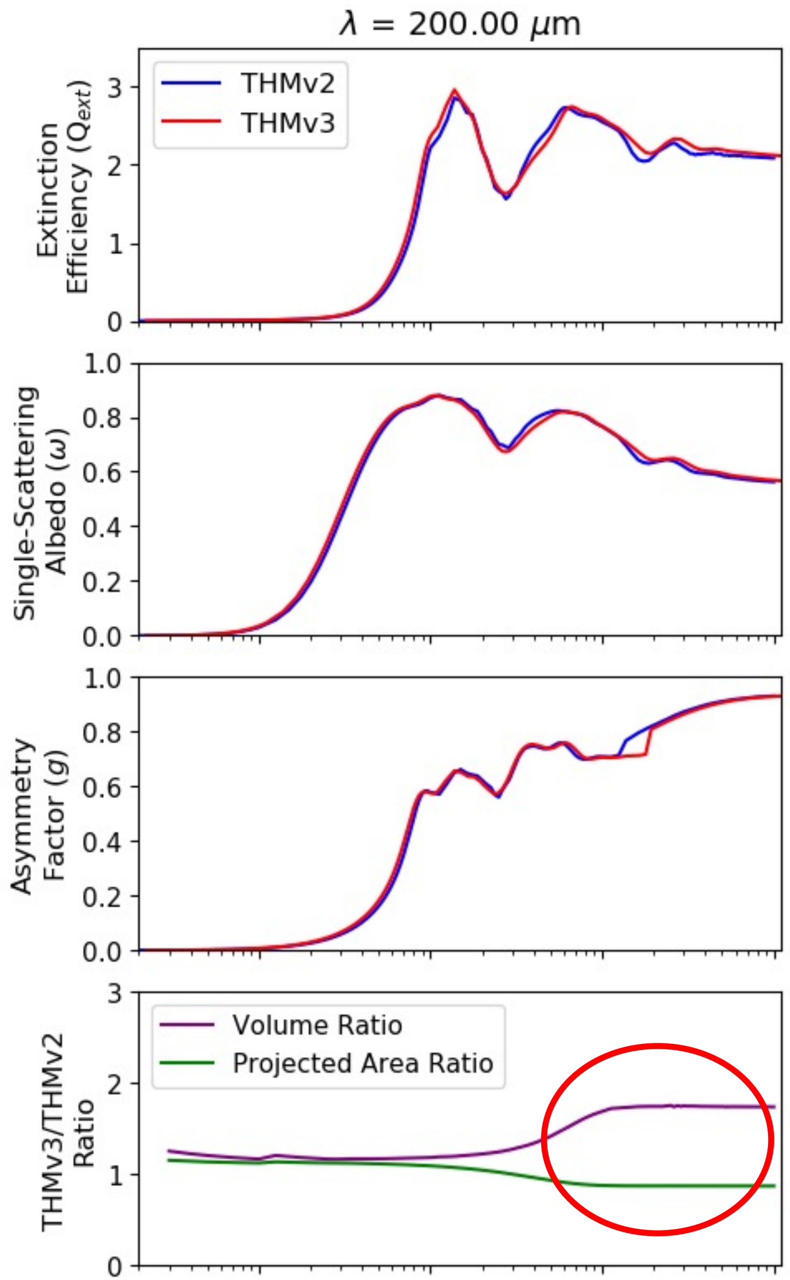
- **Converting THMv3 D_{VA} to D_{max} revealed an interesting inconsistency to THMv2.**
  - THMv3 volume increasingly inconsistent with THMv2 as D_{max} increases.
  - THMv3 projected area becomes consistent with THMv2 as D_{max} increases.
- **Determined that THMv2 aggregate volume is inaccurate.**
  - Same aggregate ensemble used for THMv3.
  - THMv3 size scaled by D_{VA} initially which is dependent on volume and projected area.
  - Inaccurate D_{VA} will result in inconsistencies in microphysical/optical properties between THMv2 and THMv3.

THMv2



THMv3

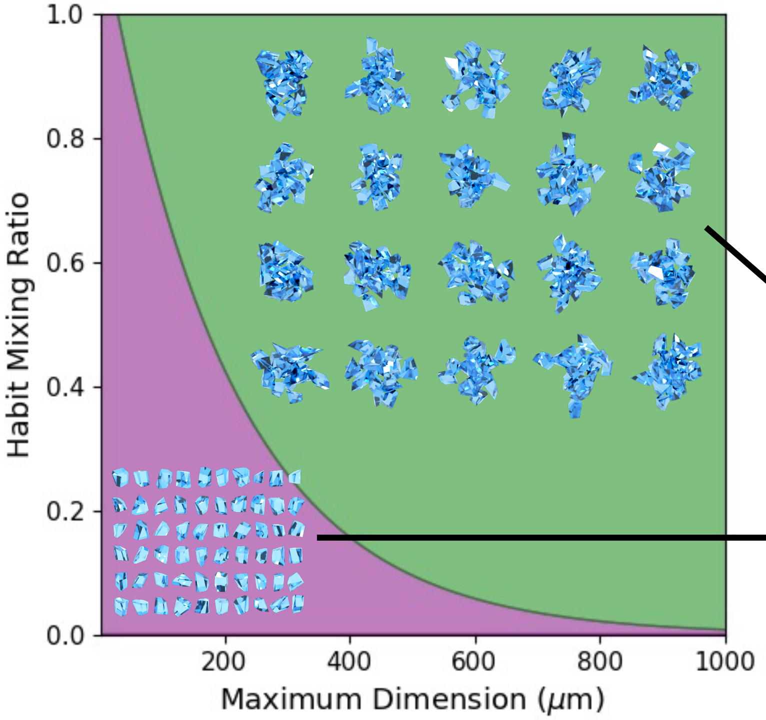
$$D_{VA} = \frac{3V}{2A_p}$$



Initial THMv3 Microphysical Consistency to Field Campaigns

- THMv3 initially followed same habit fraction formula as THMv2.
  - Dominant single column ensemble limit at 30 µm and aggregate slope at 0.005.
- Ice water content computed from THMv3 inconsistent with Ice Water Content Measured from 11 field campaigns.
- Median mass diameter generally consistent except for large values.

THMv3 Habit Fraction



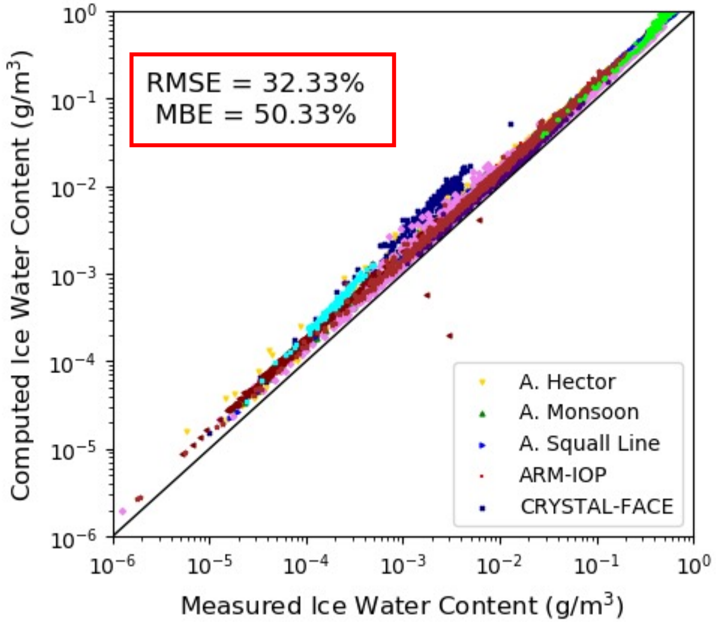
$$RMSE = \sqrt{\frac{\sum_{i=0}^{N}(x_{calc} - x_{obs})^2}{N}}$$

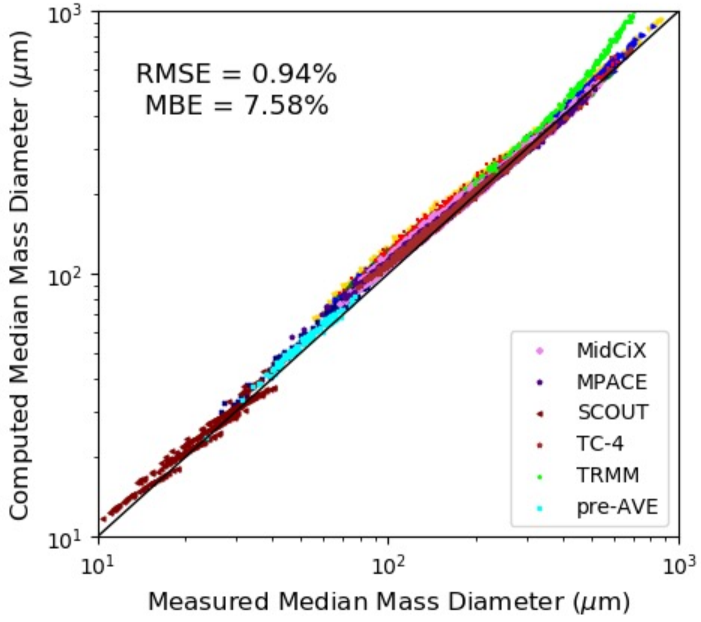
$$MBE = \frac{\sum_{i=0}^{N}(x_{calc} - x_{obs})}{N}$$

$$f_{aggregate} = 1.0 - f_{single}$$

$$f_{single} = \begin{cases} e^{-0.005(D_{max}-30)}, & D_{max} \geq 30\mu m \\ 1, & D_{max} < 30\mu m \end{cases}$$

THMv3 Microphysical Consistency

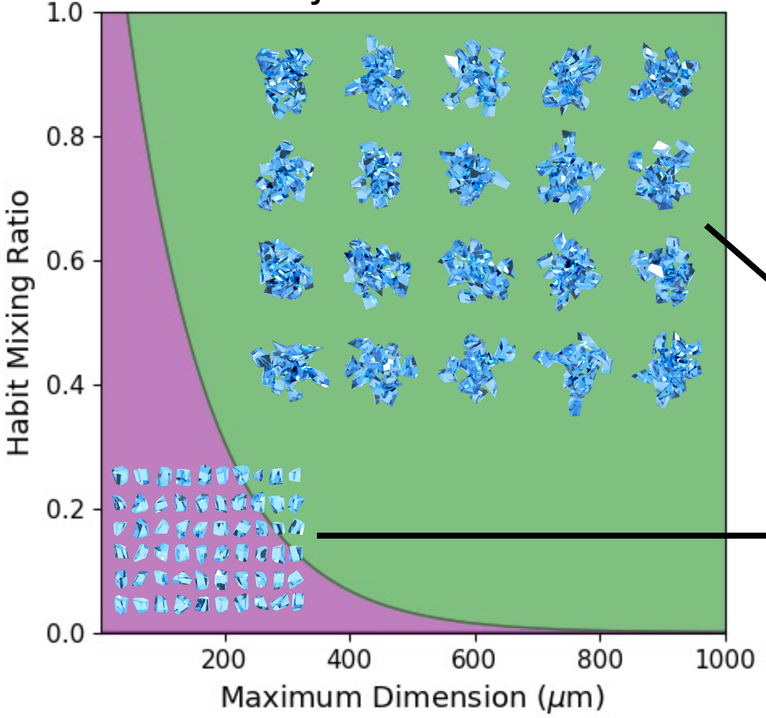




Improving THMv3 Microphysical Consistency by Adjusting Habit Fraction

- Ice water content/Median mass diameter dependent on volume.
  - THMv3 volume dependent on mixture of the 2 habit ensembles.
- Habit fraction formula adjusted to improve microphysical consistency.
  - Dominant single column ensemble limit now at 45 µm and aggregate slope at 0.0076.
  - Ice water content/Median mass diameter consistency nearly twice as improved.

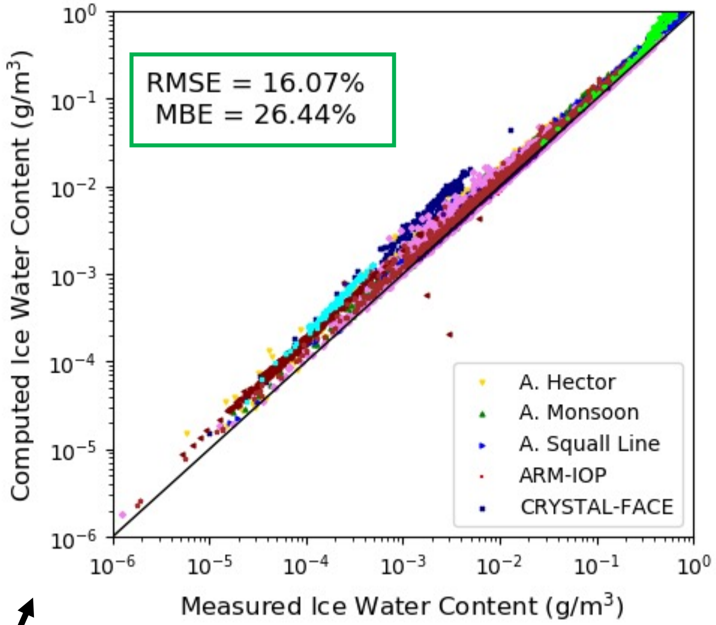
THMv3 Adjusted Habit Fraction

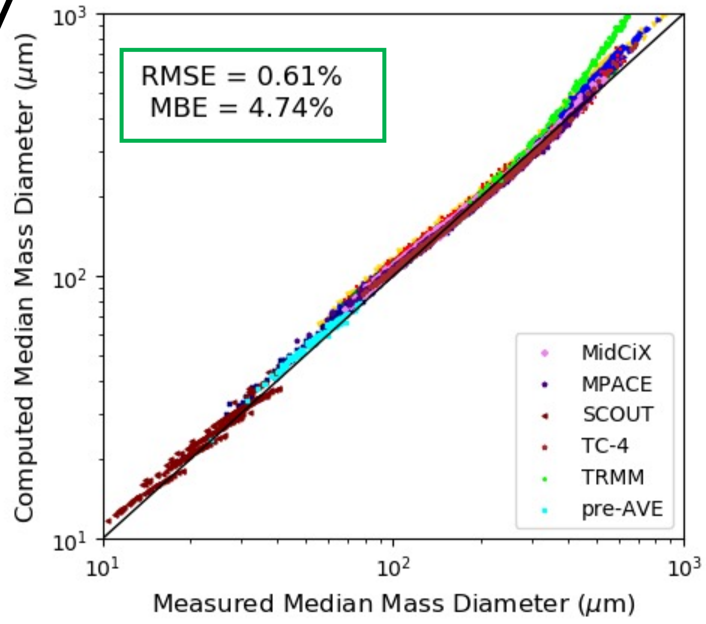


$$f_{aggregate} = 1.0 - f_{single}$$

$$f_{single} = \begin{cases} e^{-0.0076(D_{max}-45)}, & D_{max} \geq 45\mu m \\ 1, & D_{max} < 45\mu m \end{cases}$$

THMv3 Microphysical Consistency



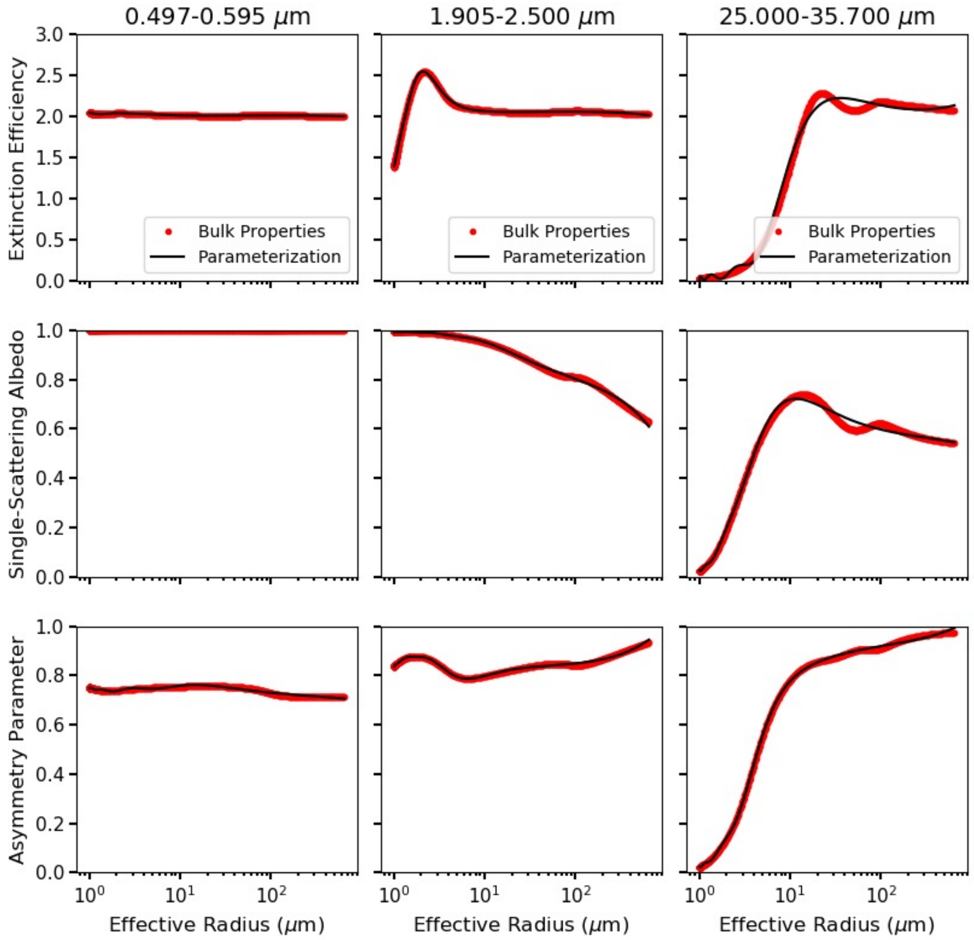


Bulk Radiative Parameterization for Fu-Liou RTM

- Parameterization performed for **18 shortwave bands and 14 longwave bands**.
- Utilizes a **10-term polynomial equation for bulk extinction efficiency, scattering albedo, and asymmetry parameter**.
  - Smaller terms fail to capture sharp fluctuations in bulk scattering properties for infrared bands.
  - Coefficients (c_i) derived from least square linear regression.

Fu-Liou Parameterization Formula

$$\langle Qext\rangle, \langle\omega\rangle, \langle g\rangle = \sum_{i=0}^{9} c_i r_{eff}^{1-i}$$

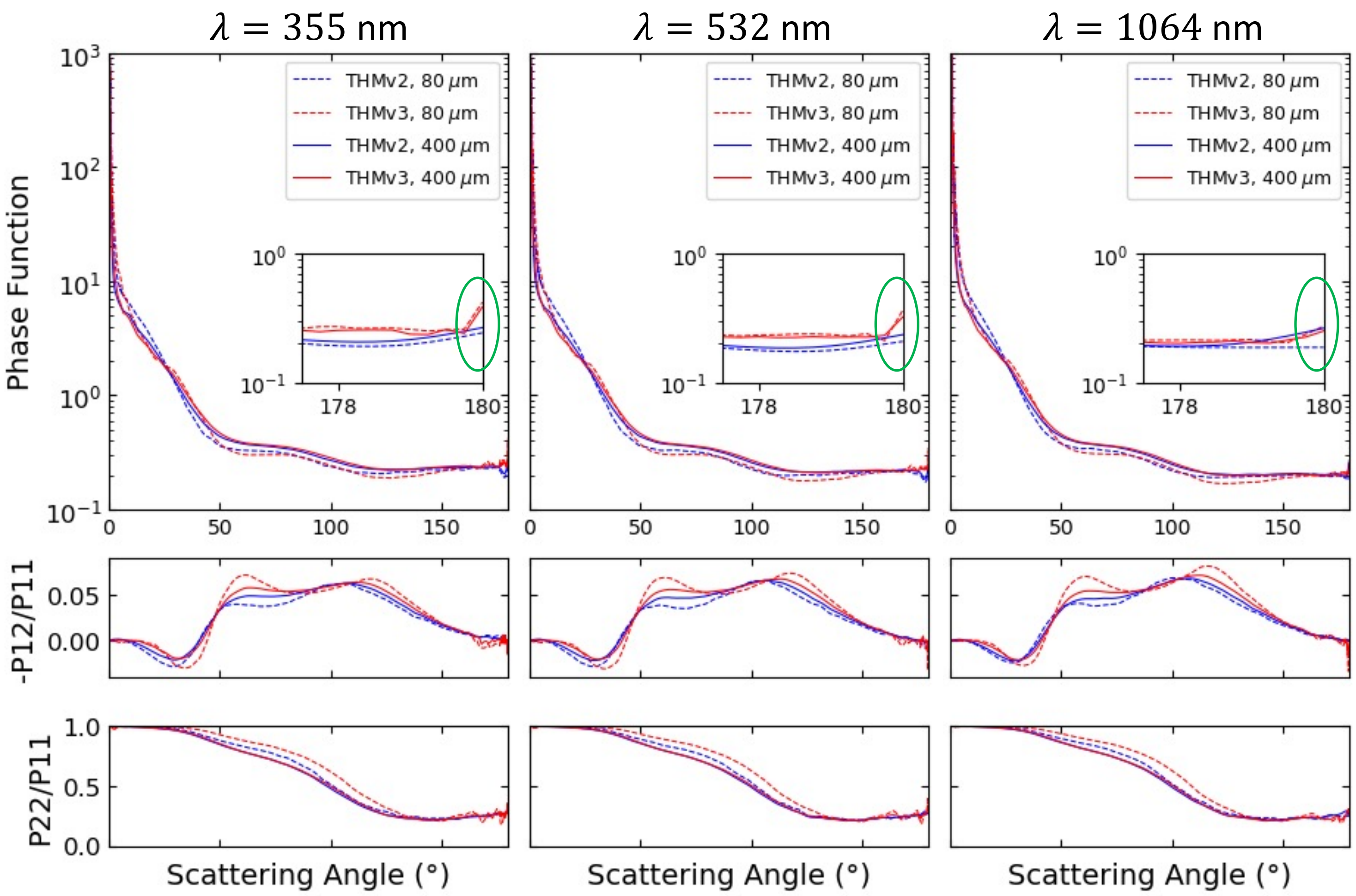


Shortwave Bands			
#	Bandwidth (μm)	Band Avg (μm)	Gases
1	0.175 – 0.224	0.21	O3
2	0.224 – 0.243	0.23	O3
3	0.243 – 0.285	0.26	O3
4	0.285 – 0.298	0.29	O3
5	0.298 – 0.322	0.31	O3
6	0.322 – 0.357	0.33	O3
7	0.357 – 0.437	0.38	O3
8	0.437 – 0.497	0.46	O3 / H2O
9	0.497 – 0.595	0.53	O3 / H2O
10	0.595 – 0.689	0.63	O3 / H2O
11	0.690 – 0.794	0.72	H2O / O2 / O3
12	0.794 – 0.889	0.83	H2O
13	0.889 – 1.042	0.94	H2O
14	1.042 – 1.410	1.16	H2O
15	1.410 – 1.905	1.57	H2O / CO2
16	1.905 – 2.500	2.10	H2O / CO2 / CH4
17	2.500 – 3.509	2.84	H2O / CO2 / O3 / CH4
18	3.509 – 4.000	3.67	H2O / CO2 / CH4

Longwave Bands			
#	Bandwidth (μm)	Band Avg (μm)	Gases
1	4.54 – 5.26	4.78	H2O
2	5.26 – 5.88	5.47	H2O
3	5.88 – 7.14	6.30	H2O
4	7.14 – 8.00	7.43	H2O / CH4 / N2O
5	8.00 – 9.09	8.36	H2O / CH4 / N2O / Cfc
6	9.09 – 10.2	9.46	H2O / O3 / Cfc
7	10.2 – 12.5	10.97	H2O / Cfc
8	12.5 – 14.9	13.30	H2O / CO2
9	14.9 – 18.5	16.10	H2O / CO2
10	18.5 – 25.0	20.67	H2O
11	25.0 – 35.7	28.57	H2O
12	35.7 – 99.0	56.80	H2O
13	3.50 – 4.00	3.67	H2O / CO2
14	4.00 – 4.50	4.18	H2O / N2O / CO2

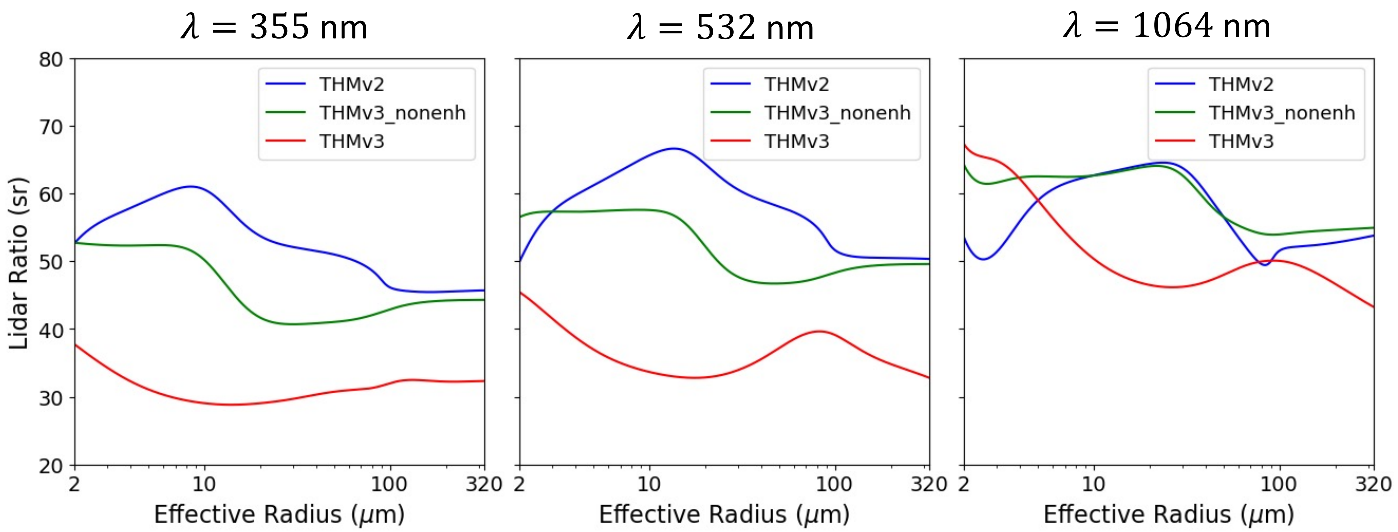
Lidar-Based THMv3 Improved Backscattering

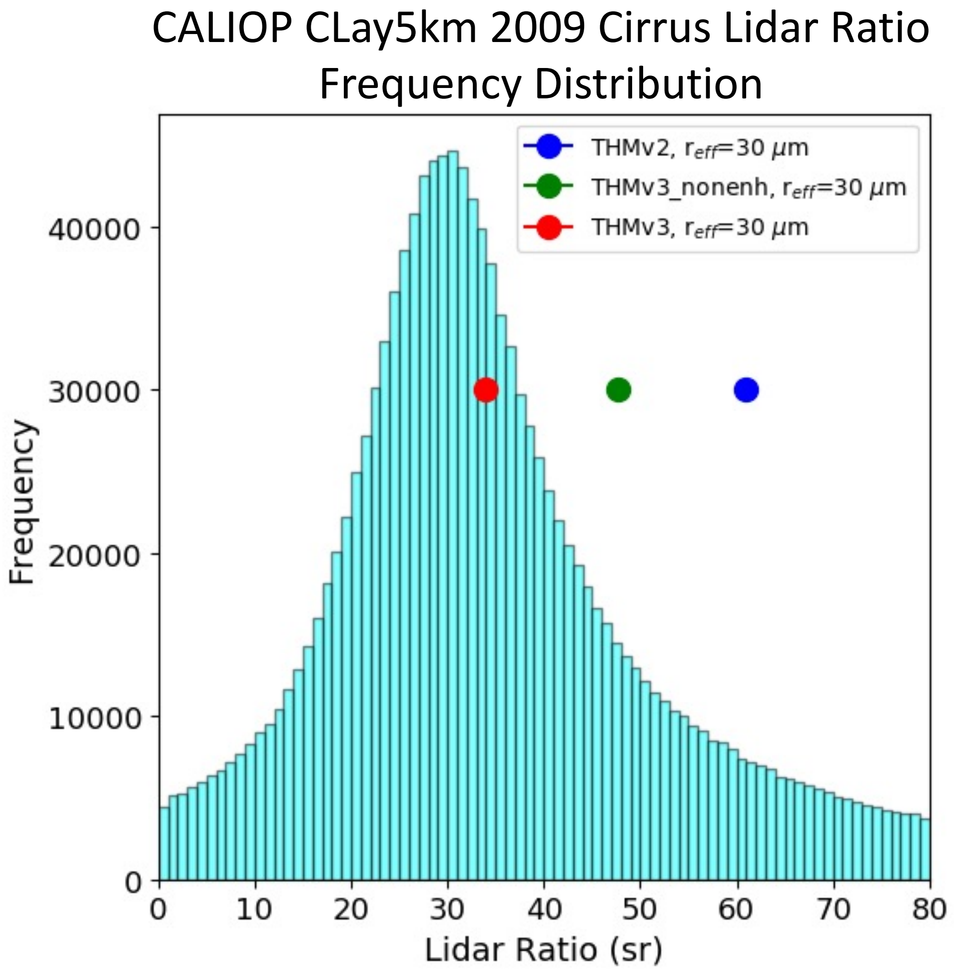
- Revisions to full resolution THMv3 also applied to lidar version.
- PGOM calculations applied to $160° - 180°$ scattering angles of phase matrix.
  - Overall greater P_{11} backscattering than THMv2.
  - THMv2 backscattering appears to match THMv3 at 1064 nm and larger sizes.



Lidar Ratio Improvements for Bulk Properties

- **THMv3 lidar ratio generally lower than THMv2 for all 3 wavelengths**.
  - Improved backscattering provided by PGOM significantly affects lidar ratio.
- 532 nm THMv3 lidar ratio more consistent with CALIOP Cloud Layer cirrus measurements.
  - More accurate lidar ratio will likely lead to improved lidar-based downstream calculations.





Summary & Future Work

- Revised the full resolution THMv3 and fully developed the lidar version THMv3.
  - Confirmed that aggregate volume is correct.
  - Adjusted habit fraction formula to improve microphysical consistency.
  - Bulk parameterization for Fu-Liou RTM completed.
  - THMv3 lidar ratio more consistent to observations due to improved backscattering.
- ***Future work:***
  - Expand PGOM calculations to 0.2 – 2.2 µm of full resolution THMv3 by using further truncated scattering angle resolution and interpolation.
    - No PGOM backscattering improvement for larger wavelengths (infrared).
    - Plan to have majority done by December.
  - Implement bulk parameterizations of THMv3 to Fu-Liou RTM and evaluate improvements in ice cloud retrievals based on satellite instruments.